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RE: Preliminary Assessment of Potential Effects on Salmonids Associated with Turbidity Caused by Dredging in the Columbia and Willamette Rivers

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Presented below is a technical memorandum that discusses the potential effects of turbidity on federally listed salmonids associated with dredging. This memorandum also presents a cursory discussion; from the published literature; of the proposed dredge types in use on the Columbia and Willamette Rivers and their potential influence on turbidity increases and effects to salmonids.

1.0 INTRODUCTION

Turbidity, an important variable of freshwater quality, can adversely affect macrobenthic invertebrate communities, fish productivity, channel morphology, and other beneficial uses (Bisson and Bilby, 1982; Newcombe and MacDonald, 1991; Barrett *et al.*, 1992). Although moderate turbidity can provide fish cover from predation, high levels can reduce feeding efficiency, food availability, clog gillrakers, and erode gill filaments (Bruton, 1985; Gregory *et al.,* 1993). Channel dredging can cause a local increase of turbidity depending on dredge type, substrate composition, and dredge productivity (USAEWES, 1988b).

With this in mind, the question of interest becomes "how much does turbidity increase during dredging operations and what effects could it have on federally listed fish species?" Because the studies available on the subject vary, we provide a general evaluation of potential effects turbidity increases may have as well as threshold guidelines for dredging operations on the Columbia and Willamette Rivers within the vicinity of the Port's facilities.

2.0 TURBIDITY EFFECTS ON SALMONIDS

Experiments have been conducted on pre-emergent, juvenile, and adult life stages of salmonids. Published literature pertaining to the effects of turbidity on salmonids can be confusing and often conflicting. Responses observed are not only dependent on the amount of turbidity but are a function of life history stage, duration of exposure, concentration of suspended sediment, particle size and angularity. Like with most chemical compounds, duration of exposure is key to understanding chronic and acute effects on any organism. Further complexities result from inconsistencies of the effects found in the literature, and the non-specific relationships between measurement devices and methods. Comparisons between various techniques in measuring refractory (i.e., nephelometric turbidity unit (NTU) or Jackson turbidity unit (JTU)) or physical characteristics (i.e., particle shape, size and dry weight) are difficult if not impossible to make.

For example, a meta-analysis published by Newcombe and Jensen (1996) presents a log-linear model based on suspended sediment concentration and duration of exposure, which predicts salmonid effects (behavioral, sublethal, lethal and paralethel). In an investigation of turbidity effects on the foraging behavior of juvenile chinook (*Oncorhynchus tshawytscha*), log-linear declines also were observed in reaction distance with increasing turbidity. In addition, foraging rates were reduced. However, at intermediate turbidity levels (35 – 150 NTU) the highest feeding rates were observed (Gregory and Northcote, 1993). Although in this case they were examining juvenile chinook, this finding seems to contrast with the findings of Bisson and Bilby (1982) that juvenile coho salmon (O. Kisutch) actively avoid turbidity over 70 NTUs when areas of clearer water are available.

The use of turbid water as cover from predators has been observed in other studies. In some instances preference for intermediate levels of turbidity has been observed when fish are frightened. Brook trout (*Salvelinus fontinalis*), for example, become more active at moderate levels of turbidity compared to clear water conditions (Bisson and Bilby, 1982).

As mentioned above, particle size and angularity are other important factors. Finer more abrasive particles tend to clog gillrakers, and erode gill filaments. Juvenile coho salmon and steelhead subjected to continuous concentrations of clay particles demonstrated reduced growth (Sigler *et al.*, 1984). The May 18, 1980 eruption of Mount St. Helens caused turbidities in the Columbia River as high as 1,500 JTU. This very fine material did affect the feeding behavior of salmonids and a majority of the fish migrated to the central and lower estuary, presumably to avoid the high turbidity (Emmett *et al.*, 1988, Kirn *et al.*, 1986). Identification of home waters by returning male chinook salmon was adversely affected by turbidity ≥ 30 NTU and/or suspended sediments from as little as 20 mg/l (Sigler, 1988) from this ash.

Another concern commonly mentioned does dredging operations cause the increase of fines in spawning gravels potentially. Although egg mortality does increase as fine sediment abundance in gravels increases, there are no suitable spawning gravels near the navigation channel and Port of Portland marine terminals on the Columbia and Willamette Rivers as the substrate is predominately sand, silty-sand and sandy-silt. The Columbia River and Lower Willamette River are used primarily as a migration corridor for salmonids.

3.0 BACKGROUND TURBIDITY

Available turbidity data for the lower Willamette River and Columbia Rivers were reviewed to generally describe background turbidity levels. Turbidity on the Willamette River at the Burlingtion Northern Railroad Bridge (RM 6.9) average 14 NTU during the winter in-water work period of December 1 – January 31 (DEQ LASAR 2001). The average monthly turbidity levels for the months of December, January, and February (1995-2000) were 16, 39 and 47 NTU respectively. Turbidity levels are generally much lower in the summer and early fall with average monthly values ranging between 4 and 8 NTU for the months of July through October. The average turbidity level during the summer in-water work period is 5 NTU. Annual background turbidity levels at this location range from 2 to 149 NTU.

Water quality data obtained by the DEQ Laboratory (DEQ LASAR, 2001) on the Columbia River at Marker 47 (RM 102.5) for the period of 1995-2000 were also reviewed. Average turbidity at Marker 47 during the winter in-water work period of November 1 – February 28 is 23 NTU. Background turbidity levels at this location during the winter range from 6 to 143 NTU.

4.0 DREDGE TYPES

The principle piece of dredging equipment used for maintenance dredging of Port of Portland marine terminals is the clamshell dredge. Two types of dredges are used on the Columbia and Lower Willamette River Federal Navigation Channel, the Cutterhead Pipeline dredge and the Hopper/dragarm dredge.

4.1 Clamshell Dredge

Clamshell dredging is performed using a bucket operated from a crane or derrick that is mounted on a barge. The Port requires the use of a tight-lipped bucket to reduce spillage and shrouding on the cables to retain sediment in the bucket and reduce the potential for resuspension. Best management practices are also routinely implemented to reduce distrubance of the sediments and resultant resuspension and turbidity. Material excavated by means of clamshell dredging is approximately 80% solids and 20% water with minimal mixing in the water column (Degens pers. comm. 2001).

The Port has previously used clamshell dredging equipment at Terminal 4, Terminal 5 and Terminal 6. Turbidity profiles recorded during dredging compliance monitoring at these facilities have not identified turbidity levels that would be detrimental to salmonids (Hancock 1995, Hart Crowser 2001).

4.2 Cutterhead dredge

The cutterhead dredge is the most commonly used dredge in the United States (Herbich, 1991). It consists of a hydraulic suction pipeline with a rotating cutterhead attached to the suction intake that mechanically assists in the excavation of consolidated material (Collins, 1995; USAEWES, 1988b). The excavated material is pumped to a designated disposal area through a pipeline, which ranges in diameter from 6 to 44 inches. The slurry of sediment and water, which is pumped through the pipeline, is generally 10 to 20 percent solids by weight (Herbich, 1991).

Field studies indicate that the cutterhead dredge is capable of removing sediment with relatively small amounts of resuspension extending beyond the immediate vicinity of the dredge (USAEWES, 1986). The mixing caused by the rotating cutterhead is the main contributor to sediment resuspension, however, the blades are designed to direct the loosened material towards the suction intake. If the suction intake velocity is sufficient to remove all of the sediments excavated by the blades, very little suspended material will enter the water column (USAEWES, 1988b). Sediment resuspension by a cutterhead dredge can also be minimized by proper selection of the cutter rotation speed, ladder swing speeds, and depth of cut (USAEWES, 1986).

Sediment resuspension from cutterhead dredges is primarily in the lower portion of the water column. Measurements from a dredging project at Calumet Harbor showed a maximum increase of suspended sediment concentration 3 to 5 mg/l above background at

100% depth and 1 to 3 mg/l above background at 50% depth. These measurements were taken within the immediate vicinity of the cutterhead (USAEWES, 1988b).

4.3 Hopper/dragarm dredge

Hopper dredges use a hydraulic suction line and draghead to excavate river bottom substrate. This material is pumped through a series of hoppers located in the vessel hull. Sediments settle in the hoppers and the excess water is allowed to overflow back into the river during overflow operations. The overflow water may be very turbid depending upon the grain size of the substrate material (USAEWES, 1988b).

Hopper dredges provide two sediment sources: the draghead and overflow. Only one study has been conducted involving the sediment resuspension associated with hopper dredging, thus, little quantitative information is available. Further, the drag arm is located beneath the dredge, making it difficult to measure resuspension near the draghead (USAEWES, 1988b). The study conducted in Grays Harbor, WA indicates that during nonoverflow operating mode sediment resuspension may be less than for a cutterhead dredge. However, during overflow operating mode, hoppers can create a turbidity plume behind the dredge when dredging materials do not settle rapidly in the hoppers bins (Collins, 1995).

Measurements taken during hopper dredge (overflow) operations in Grays Harbor, WA indicated high suspended sediment concentrations near the top of the water column and concentrations of 700 mg/l near 100% depth as background concentrations ranged from 28 to 60 mg/l. Boats anchored behind the dredge measured the decay of the sediment plume and determined that it was a function of time or distance behind the dredge (USAEWES, 1988b).

5.0 EFFECTS BASED TURBIDITY THRESHOLDS

Turbidity is often used to monitor water quality downstream of dredging operations. Oregon guidelines state that turbidity should not exceed background by more than 10 percent. However, these guidelines do not detect the least change in concentration capable of causing ill effects to salmonids, nor do they adequately handle the dynamic flux of sediment inherent in aquatic ecosystems.

5.1 Turbidity, Total Suspended Solids Correlation

The response model developed by Newcombe and Jensen (1996) uses the concentration of suspended sediment or total suspended solids (TSS) in mg/L and duration of exposure to predict salmonid effects. However, in a regulatory context; turbidity, measured using the nephelometric turbidity unit (NTU), is most commonly used because of it's relation to ocular estimates and relative ease of use. TSS is generally tightly correlated to turbidity. The correlation of TSS and turbidity is dependent upon site-specific factors including particle size, shape and color.

Hart Crowser (2001) developed a TSS/turbidity rating equation for the Port's Terminals 2, 5, and 6. TSS levels in the following section are converted to turbidity using the following site-specific relationship:

$$\text{Turbidity (NTU)} = 1.81(\text{TSS})$$

This linear relationship was based on a sample size of 40 and had coefficient of determination R^2 of 0.89.

5.2 Threshold Levels

Ross Island Sand and Gravel developed turbidity thresholds as part of their monitoring and management program for their facility in the Willamette River. This effects based approach has been accepted by the Oregon Department of Environmental Quality as being sufficiently protective of all beneficial uses and as satisfying the requirements for turbidity contained in OAR 340-041-0445. The approach described herein is similar to that used by Ross Island Sand and Gravel, using the site-specific rating equation described in Section 5.1.

Turbidity thresholds presented in Table 1 are based on an extensive literature review, the response model developed by Newcombe and Jensen (1996), and seasonal acclimation turbidity levels present in the Columbia and Willamette Rivers. Although much of the data regarding the effects of turbidity on salmonids is conflicting, a conservative approach was taken when developing these threshold levels to assure that salmonids would not be harmed by the Port's dredging operations. For example, the thresholds assume that salmonids would be trapped within the area of elevated turbidity when, in fact, they may simply swim away from the area. In addition, the turbidity thresholds are selected based on the ranking used by Newcombe and Jensen (1996) such that no salmonids assumed to be trapped within the area of elevated turbidity would suffer anything more than "minor physiological stress" (a severity of 5 on a scale of 0 through 14).

Threshold limits include an action level and a stop-work level. The action level is a threshold level that would trigger implementation of action steps designed to reduce turbidity levels resulting from the activity. The stop-work level is a threshold level that would require a temporary shutdown.

Table 1. Threshold levels for the Willamette River and Columbia River in the vicinity of the Port of Portland's marine facilities during the allowed in-water work periods.

Turbidity Level (NTU)	Willamette River		Columbia River
	Jul 1 – Oct 31	Dec 1 - Jan 31	Nov 1 – Feb 28
Action Level (48-hour average)	35	44	53
Stop Work Level (8-hour average)	135	144	153

Absent of seasonal acclimation turbidity levels for each river system during the in-water work periods specified above, the action level for a duration of 48-hours is 30 NTU and the stop work level for a duration of 8-hours is 130 NTU. These threshold levels could be used throughout the year in either the Willamette or Columbia Rivers to assure that there would be no detrimental effects to salmonids.

6.0 CONCLUSIONS

Turbidity increases caused by dredging operations tend to be localized, largely in the lower portion of the water column where the cutterhead or drag arm is removing the sediments. A clamshell dredging may increase turbidity in the water column through which the dredge is operating. Dredging induced turbidity, compared to natural fluctuations in suspended sediment concentrations, would be a minor constituent in the Willamette or Columbia River systems. Dredging at the Port's marine terminals is temporary and occurs at isolated facilities. It is unlikely to coincide with other dredging projects immediately downstream of, upstream, or across the river from the proposed projects. Therefore, it is not anticipated that the cumulative impact of dredging induced turbidity would be so large as to not allow fish an escape route.

Because of the design of the proposed dredge equipment, turbidity monitoring of the dredging operations, location of dredging activities in relationship to primary salmonid spawning and rearing habitats, and short duration of salmonid exposure, impacts to water quality and fish populations should be negligible. Compliance monitoring using an affects based turbidity threshold approach and the associated best management practices will assure that dredging induced turbidity will not be detrimental to salmonids.

7.0 REFERENCES

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